Annual Report for AOARD Grant FA2386-11-1-4113 "Development of Silicon-Based Group IV Lasers"

17/8/2012

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Period of Performance: 22/8/2011 – 22/8/2013

Abstract:

The objective of the project is to develop silicon-based group IV heterostructure lasers by the incorporation of another group IV element of Sn. We have made significant progress toward the milestones described in the proposal. Optical emitter made of P-i-N diode with direct bandgap is fabricated. The structure has been characterized by various measurements to establish that emitting layer is direct bandgap. We are forwarding herewith the detection of emission on the device, if this is realized, then we could have a breakthrough on Si-based optical emitter.

This report is organized as following sections:

(a) Material growth

(b) P-i-N heterostructure

(c) Characterization on the structure

(d) Future direction of work

(e) Publications

(a) Material growth

On the material growth, different structures are grown by molecular beam epitaxy. First, we investigate different type of doping in GeSn alloy for serving as p- and n-type dopant. Magneto-Hall measurement is performed to identify the dopant. Then, we proceed with optical emitter made of P-i-N diode using the growth techniques of low temperature growth and virtual buffer. (For a detail description of these techniques, see Local intermixing on Ge/Si heterostructures at low temperature

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
17 SEP 2012	**Annual**	**22-08-2011 to 20-08-2012**

4. TITLE AND SUBTITLE	
Development of Silicon-Based Group IV Lasers	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Hung Hsiang Cheng**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **National Taiwan University,1, Roosevelt Road, Section 4,Taipei 10764,Taiwan,NA,NA**	8. PERFORMING ORGANIZATION REPORT NUMBER **N/A**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **AOARD, UNIT 45002, APO, AP, 96338-5002**	10. SPONSOR/MONITOR'S ACRONYM(S) **AOARD**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **AOARD-114113**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The objective of the project is to develop silicon-based group IV heterostructure lasers by the incorporation of another group IV element of Sn. The researchers have made significant progress toward the milestones described in the proposal. Optical emitters made of P-i-N diode with direct bandgap were fabricated. The structure has been characterized by various measurements to establish that emitting layer is direct bandgap. They are forwarding herewith the detection of emission on the device, if this is realized, then they could have a breakthrough on Si-based optical emitter.

15. SUBJECT TERMS

Electronic Materials, Heterostrucuture Semiconductor, Light Emitting Devices, Molecular Beam Epitaxy

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

growth, H. H. Cheng, W. P. Huang, V.I. Mashanov, and G. Sun, J. Appl. Phys. 108, 044314 (2010).) The device consists of four layers: (a) a Ge layer grown at low temperature, (b) a n-type GeSn virture substrate, (c) Ge layer grown at a normal temperature of 600°C and, (d) a p-type GeSn layer. The lattice constant of Sn is about 15% larger than that of Ge. As a result, the Ge layers is tensily strained. Layer (b) and (d) serves as electrical contact for the diode. Systematic investigation is performed on various Sn compositions in order to obtain the structure with a direct-bandgap emitting layer.

(b) P-i-N heterostructure

In the literature, the photoluminescence emission intensity of Sn-based group IV compounds is weak as mainly attributed to the low carrier densities excited by the optical pumping. For example, with a laser of about 10 mW, the excitation gives ~10^{10}/cm^3 carrier in the sample. This is several orders of magnitude smaller than the typical carrier density used in the electrically pumped emission diode. Thus, a p-i-n diode structure would give a much stronger optical signal. The p-i-n diode is fabricated in our laboratory and the structure consists of GeSn/Ge/GeSn with different Sn compositions. A typical cross-sectional transmission electron microscope (TEM) image of the device is shown in fig. 1.

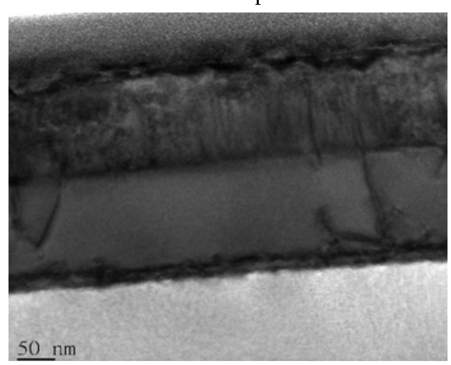

Fig. 1. TEM image of the device made of p-i-n diode structure.

(c) Characterization on the structure

Various measurements have been performed to characterize these samples, including microstructure analysis of high resolution X-ray, optical spectroscopy, etc. Here, we present the absorption spectrum measured by Fourier transform infrared spectroscopy (FTIR) to establish the directness of the energy band of the i-layer. The spectra with different Sn compositions

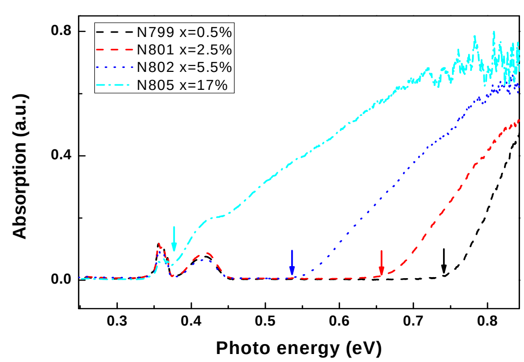

Fig. 2. Absorption spectrum of the i-layer of the p-i-n diode.

are plotted fig. 2. The absorption edge of the i-layer (as marked by the solid arrow) shifts to lower energy as Sn composition increases. From the analysis, it shows that the energy band of the i-layer (Ge) is direct as Sn＞5.5%.

(d) Future direction of work

In this year, we focus on: (a) exploring the p-i-n diode structure for practical optical emitter, and (b) characterization of the structure to establish a direct bandgap emitting layer. In the next stage, we will carry out emission measurement to probe possibility of using the diode as optical emitter.

(e) Publications

(1) Formation of Ge-Sn nanodots on Si(100) surfaces by molecular beam epitaxy, Vladimir Mashanov, Vladimir Ulyanov, Vyacheslav Timofeev, Aleksandr Nikiforov, Oleg Pchelyakov, Ing-Song Yu and Henry. H. Cheng, Nanoscale Research Letters, Vol. 6, p. 85. (2011).

(2) Investigation of Ge1-xSnx/Ge with high Sn composition grown at low-temperature, I. S. Yu, T. H. Wu, K.Y. Wu, H. H. Cheng, V. I. Mashanov, A. I. Nikiforov, O. P. Pchelyakov, and X. S. Wu, AIP ADVANCES **1**, 042118 (2011).

(3) Strain analysis of a wrinkled SiGe bilayer thin film, Guo-En Chang, Chia-Ou Chang, and H. H. Cheng, J. Appl. Phys. 111, 034314 (2012).

(4) Clustering Effect on The Band Gap of GeSn Alloys, Journal of Nanoelectronics and Optoelectronics

(5) Transformation of a two-dimensional to one-dimensional energy profile on a spatially deformed $Si_{0.82}Ge_{0.18}/Si_{0.51}Ge_{0.49}$ wrinkled heterostructure, Guo-En Chang, H. H. Cheng, G. Sun, and R. A. Soref, J. Appl. Phys. 111, 104321 (2012).

(6) Franz-Keldysh Electro-Absorption Modulation in Germanium-Tin Alloys, R. A. Soref and G. Sun, and H. H. Cheng, 111, 123113, J. Appl. Phys. (2012).